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(54) Spectrum management

(57) A frequency spectrum manager is connected to a cellular radio communications system and provides real time management of radio spectrum. The wireless communications system comprises a plurality of base stations connected to a central office, with each of the radio base stations configured to communicate with mobile end units using a portion of the radio spectrum. The central office stores spectrum usage information from each of the base stations. The frequency spectrum manager receives the spectrum usage information from the central office, analyzes the information, and instructs the central office to reconfigure the radio base stations based on the spectrum usage information. The frequency spectrum manager can be used to manage the spectrum for a single wireless communications service (e.g. analog cellular telephone), or may be connected to the central offices of multiple services (e.g. analog cellular telephone, digital cellular telephone, cellular digital packet data) to manage the spectrum across the multiple services.

FIG. 1

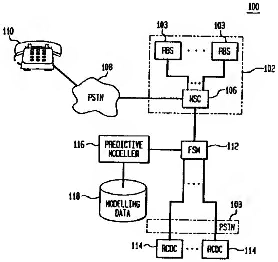

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FIG. 1

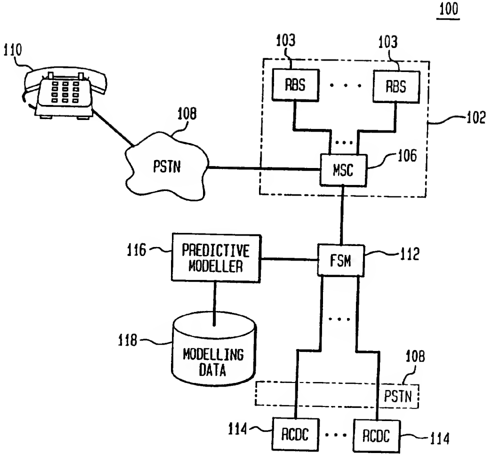

100
110
103
103
RBS
RBS
108
102
PSTN
MSC
106
116
PREDICTIVE MODELLER
FSM
112
118
MODELLING DATA
108
PSTN
114
RCDC
RCDC
114

FIG. 2

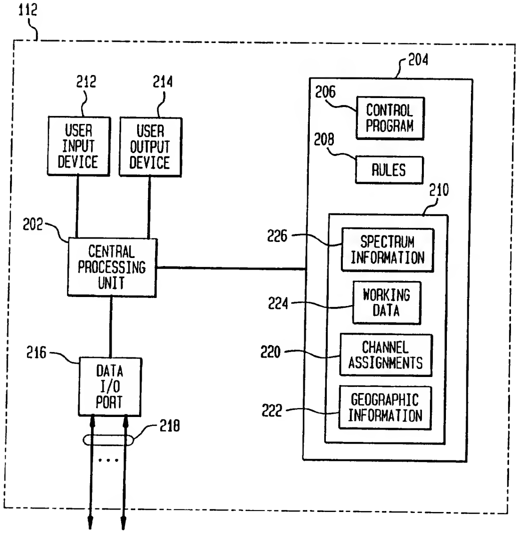

112
204
206
CONTROL PROGRAM
208
RULES
210
212
214
USER INPUT DEVICE
USER OUTPUT DEVICE
202
CENTRAL PROCESSING UNIT
226
SPECTRUM INFORMATION
224
WORKING DATA
220
CHANNEL ASSIGNMENTS
222
GEOGRAPHIC INFORMATION
216
DATA I/O PORT
218

FIG. 3

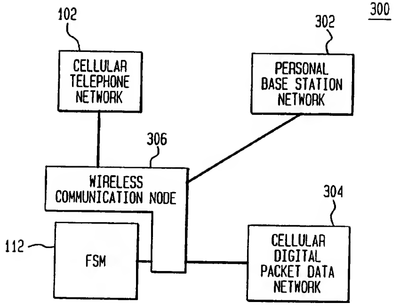

300
102
CELLULAR TELEPHONE NETWORK
302
PERSONAL BASE STATION NETWORK
306
WIRELESS COMMUNICATION NODE
304
112
FSM
CELLULAR DIGITAL PACKET DATA NETWORK

FIG. 4

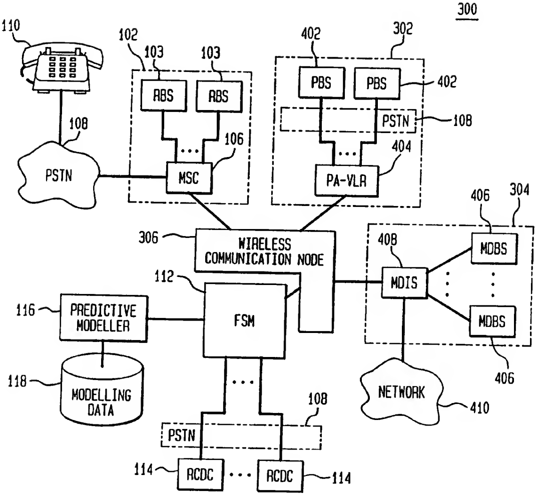
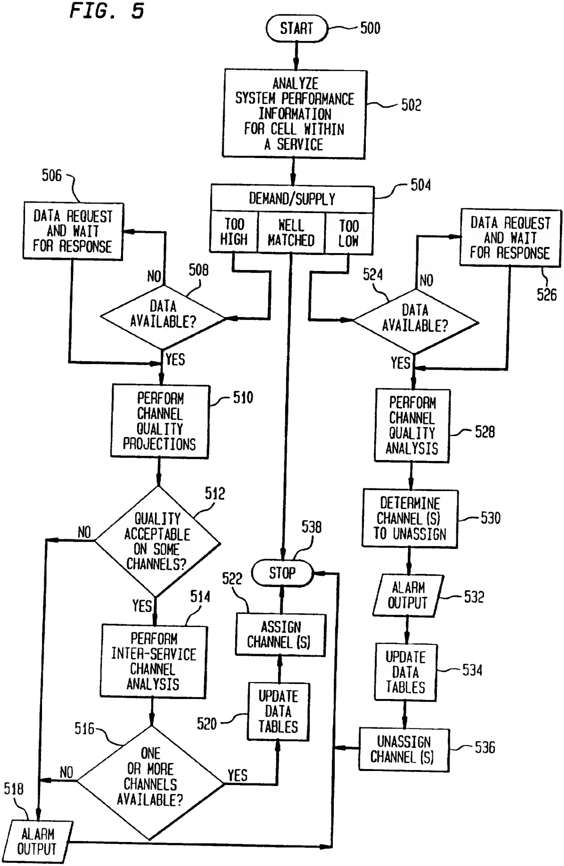

300
110
102
103
103
RBS
RBS
402
302
PBS
PBS
402
108
PSTN
108
106
404
PSTN
MSC
PA-VLR
406
304
306
WIRELESS COMMUNICATION NODE
408
MDBS
112
MDIS
116
PREDICTIVE MODELLER
FSM
MDBS
118
MODELLING DATA
406
NETWORK
410
108
PSTN
114
RCDC
RCDC
114

FIG. 5


START
500
ANALYZE SYSTEM PERFORMANCE INFORMATION FOR CELL WITHIN A SERVICE
502
DEMAND/SUPPLY
504
TOO HIGH
WELL MATCHED
TOO LOW
506
DATA REQUEST AND WAIT FOR RESPONSE
NO
508
DATA AVAILABLE?
YES
PERFORM CHANNEL QUALITY PROJECTIONS
510
512
QUALITY ACCEPTABLE ON SOME CHANNELS?
NO
YES
514
PERFORM INTER-SERVICE CHANNEL ANALYSIS
516
ONE OR MORE CHANNELS AVAILABLE?
NO
YES
518
ALARM OUTPUT
520
UPDATE DATA TABLES
522
ASSIGN CHANNEL (S)
538
STOP
524
DATA AVAILABLE?
NO
YES
DATA REQUEST AND WAIT FOR RESPONSE
526
PERFORM CHANNEL QUALITY ANALYSIS
528
DETERMINE CHANNEL (S) TO UNASSIGN
530
ALARM OUTPUT
532
UPDATE DATA TABLES
534
UNASSIGN CHANNEL (S)
536

METHOD AND APPARATUS FOR SPECTRUM MANAGEMENT

Field of the Invention

The present invention relates generally to a method and apparatus for radio spectrum management. More particularly, the present invention relates to a method and apparatus for automatically managing radio spectrum used to provide wireless communications services.

Background of the Invention

Wireless communications in general, and wireless cellular communications systems in particular, are becoming increasingly popular. Originally, cellular communications systems were used to provide analog mobile telephone services. Today, cellular communications systems provide various wireless communications services. As used herein, the term wireless communication service is used to identify any logically discreet use of the wireless spectrum. For example, wireless services include analog mobile telephone service, digital mobile telephone service, and cellular digital packet data (CDPD) services.

Cellular communication systems are well known, and generally include cell sites, each of which serves a coverage area, or cell. The cell site is the location within a cell which contains the hardware (e.g. antenna(s) and radio base station) required to communicate with mobile end units (e.g. wireless mobile telephone or wireless mobile data terminal). A mobile end unit operating within a particular cell in the system communicates with the cellular system through the cell site covering that cell. The various cell sites are connected to one or more mobile switching centers (MSC) which connect the cellular system to a land-line network. In the case of

a cellular telephone network, the land-line network is the public switched telephone network (PSTN). In the case of a CDPD network, the land line network may be the PSTN or some other type of data network (e.g. the Internet).

Wireless communication service providers are generally licensed to operate a wireless system in a particular geographic area using a specified frequency spectrum for radio communication between mobile end units and base stations. For example, a typical wireless service provider may have a license to operate in a 12.5 MHz spectrum. This spectrum may be divided into 416 channels, each 30 KHz wide. Each of these 416 channels is capable of handling the communication between one mobile end unit and a radio base station. For further information on cellular air interface, see, EIA/TIA Standard 553, "Mobile Station-Land Station Compatibility Specification", September 1989, Electronic Industries Association, Washington, D.C.; EIA/TIA Interim Standard IS-54-B "Cellular System Dual-Mode Mobile Station - Basestation Compatibility Standard", April, 1992, Electronic Industries Association, Washington, D.C.; and EIA/TIA Interim Standard IS-136 "Cellular System Dual-Mode Mobile Station - Basestation: Digital Control Channel Compatibility Standard", April, 1995, Electronic Industries Association, Washington, D.C., which are incorporated herein by reference.

Most wireless systems in use today are fixed channel cellular systems. A fixed channel cellular system is a cellular system in which each cell is assigned a fixed group of channels for communication. For example, if each cell within a cellular system were assigned a group of 34 channels, there could be a maximum of 416/34 = 12.24 or approximately 12 cells carrying the permissible 416 calls in the serving area if there was no channel reuse. However, if cells are sufficiently spaced apart, in terms of geographic ground distance, channels can be reused in

multiple cells without overlap. Designing a fixed cell system which reuses channels is a complex task. One problem with a fixed system is that cellular traffic is not always constant. Thus, the characteristics of a cell site may be such that the cellular traffic at the site may not be consistent during the course of a day or week. Further, over time, the overall characteristics of cellular traffic at a site may change such that the daily and weekly usage patterns in general may change.

When a cellular system is initially installed in a geographic area, the channels are allocated among the cell sites based on estimated demand. As the system operates, information about radio spectrum usage in the system is collected and stored in a database in the mobile switching center. After the system has been installed for a period of time, a person (generally an engineer) will analyze the stored spectrum information. The engineer may look at statistics such as blocking rate (the rate at which users attempting to use the cellular system are blocked), dropped call rate (the rate at which calls are prematurely dropped), attempt failures (user requesting a communication channel but not receiving one), page failures (a paging system failing to complete a page to a paging unit), out of service statistics (how often a channel is taken out of service due to unacceptable quality), and bit error rate (error rate on digital channels). Based on this information, the engineer may determine that channel reallocation is necessary. For example, it may be determined that another channel is required at a particular cell site. If this is the case, the engineer must then go on to determine an appropriate channel to allocate to the cell site. This requires an analysis of potential interference with other cell sites using that channel. The alteration of the channel assignments in a fixed system is a complex and time consuming task, which generally requires the expertise of a radio frequency (RF) engineer or other competent person. Manual reallocation of channels, as described above, is particularly

difficult to perform in real time, and thus cannot take into account the variability of communication traffic on a short term basis.

To more efficiently use the limited frequency spectrum, schemes other than fixed channel systems are also being studied. One such scheme is called *adaptive channel allocation*. In an adaptive channel allocation system, the cells are not assigned a fixed group of channels. Instead, the cellular system is self organizing in that each cell dynamically determines which channels it will use for communication. Thus, the system adapts itself based upon the communication traffic. The problem with current adaptive channel allocation schemes is that a cell site dynamically determines which channels it will use for communication without communicating with other cell sites. As a result, the overall efficiency of the spectrum use is limited.

Another difficulty in the maintenance of wireless systems is the sharing of radio spectrum among different services. As described above, wireless service providers are increasing the types of wireless services they provide. However, the spectrum available to provide these services is not increasing at the same pace. Thus, a single wireless service provider must share the same spectrum among different services, such as analog mobile telephone service, digital mobile telephone service, and, mobile CDPD service. As is the case with cellular telephone systems, CDPD systems are generally fixed channel systems, such that the cell sites are assigned certain fixed channels, and these fixed channels are dedicated to CDPD service. (It is noted that CDPD systems often share base station hardware with cellular telephone systems.) Again, a problem exists in that the demand for the different types of services may vary over time. As a result, engineers need to study spectrum usage and periodically need to reallocate channels

among the cell sites and among the various services. The reallocation of channels over multiple services is even more complex and time consuming than reallocating channels in a single service system.

As described above, frequency spectrum is limited, and the frequency spectrum licensed to a wireless communication service provider is a highly valuable resource which must be managed efficiently.

Summary of the Invention

The present invention provides a real time method and apparatus for managing the frequency spectrum within, and across, wireless services, in order to make more efficient use of radio spectrum.

In a single wireless service embodiment, a frequency spectrum manager device is in communication with a switching office of a wireless communication system. The switching office is in communication with a plurality of radio base stations, each of which are capable of communicating with mobile end units over a plurality of radio channels. Each of the radio base stations has a set of radio channels which the radio base station uses for communicating with the mobile end units. This set of radio channels defines the radio channel configuration of the radio base station. A memory unit stores spectrum information which is received by the switching office from the base stations. Such spectrum information may include, for example, the blocking rate at the base station, or measured spectrum characteristics at the geographic location of the base station. In an advantageous embodiment, the memory unit is contained in the switching office. The frequency spectrum manager receives the spectrum information from the switching

office, analyzes the information based on stored rules, and sends base station reconfiguration commands to the switching office based on the analysis of the spectrum information.

In addition, remote data collectors which are capable of measuring the radio spectrum in a geographic location may be provided, which communicate with the frequency spectrum manager. The frequency spectrum manager receives spectrum information from these remote data collectors and analyzes this spectrum information in conjunction with the spectrum information received from the switching office in order to make reconfiguration command determinations.

In a multiple wireless communication services embodiment, the frequency spectrum manager is in communication with the switching offices of a plurality of wireless communication services. The frequency spectrum manager receives spectrum information related to the services, analyzes the information, and makes reconfiguration determinations based on the analysis. In such an embodiment, the frequency spectrum manager makes determinations taking into consideration the needs of the different services, and how the services interact with each other.

These and other advantages of the invention will be apparent to those of ordinary skill in the art by reference to the following detailed description and the accompanying drawings.

Brief Description of the Drawings

Fig. 1 shows a cellular communications system in accordance with the single service embodiment of the present invention.

Fig. 2 shows a block diagram of the components of the frequency spectrum manager.

Fig. 3 shows a block diagram of a cellular communications system in accordance with the multiple service embodiment of the present invention.

Fig. 4 shows additional details of the cellular communications system shown in Fig. 3.

Fig. 5 is a flowchart of an exemplary rule algorithm implemented by the frequency spectrum manager.

Detailed Description

Fig. 1 shows a cellular communications system 100 in accordance with the single service embodiment of the present invention. A cellular telephone network 102 is shown comprising a plurality of radio base stations (RBS) 103, each of which is in communication with a mobile switching center (MSC) 106. Such communication may be provided by a direct connection between the RBS 103 and the MSC, as shown in Fig. 1. Such cellular telephone networks are well known in the art, and the detailed operation and architecture of such a system will not be discussed herein. It will be recognized by those skilled in the art that there may be multiple MSCs 106 within the cellular telephone system 102, each of which would have at least one RBS 103 in communication with it. Only one MSC 106 is shown in Fig. 1 to simplify the figure.

As is well known, the MSC 106 controls the functioning of the RBSs 103. Such control includes the assignment of radio channels which each RBS 103 will use to communicate with mobile end units. As used herein, a mobile end unit is any mobile device which communicates with a wireless communication system. For example, in the cellular telephone network 102 shown in Fig. 1, a mobile end unit could be a mobile cellular telephone. The MSC 106 is connected to the public switched telephone network (PSTN) 108, such that a mobile end unit

may communicate with a land line telephone 110. For more information on cellular telephone systems see, The Cellular Radio Handbook, by Neil Boucher, ISBN: 0-930633-17-2, Quantum Publishing, Mendocino, CA, June 1990; and Mobile Cellular Telecommunications Systems, by William C. Y. Lee, ISBN: 0-07-037030-3, McGraw Hill Book Company, 1989, which are incorporated herein by reference.

In accordance with the principles of the present invention, a frequency spectrum manager (FSM) device 112 communicates with the wireless telephone network 102 via the MSC 106. As will be described in further detail below, the FSM 112 receives spectrum information which was collected by the MSC 106. Alternatively, the FSM 112 may receive spectrum information from the RBSs 103 directly. The FSM 112 may also receive spectrum information from one or more remote commandable data collectors (RCDC) 114. These RCDCs 114 are devices which may be positioned within the geographic service area of the wireless communication system, and which measure the radio spectrum in the geographic location in which they are placed. The radio spectrum measurements taken by the RCDCs 114 may include, for example, the signal strength of various channels in use in the geographic location. The RCDCs 114 are used in order to collect spectrum information in addition to the spectrum information collected by the MSC 106 through the RBSs 103. The RCDCs 114 may be directly connected to the FSM 112, they may be connected through the PSTN 108, or they may communicate with the FSM through a wireless communication channel. The RCDCs 114 are advantageously of the type described in copending United States patent application serial no. 08/525,873 entitled Method And Apparatus For Spectrum Analysis, filed September 8, 1995, which is incorporated herein by reference. The data

received from the RCDCs 114 may be pre-processed before it is sent to the FSM 112 in accordance with the techniques described in the above referenced patent application.

During operation, the MSC 106 stores system performance information for the RBSs 103. Such system performance information may include:

- The channels assigned to each RBS 103. The set of channels assigned to a RBS defines the radio channel configuration of the RBS.
- The blocking rate of each RBS 103. A communication between a mobile end unit and an RBS is blocked if there are no available channels on which the mobile end unit and the RBS can communicate.
- The dropped call rate of each RBS 103. The dropped call rate measures calls in progress which are prematurely dropped by the RBS 103.
- The attempt failure rate of each RBS 103. The attempt failure rate measures users who request a communication channel but do not receive one.
- Out of service statistics for channels allocated to RBS. Out of service statistics measure how often a channel is taken out of service due to unacceptable quality.
- Bit error rate statistics for digital channels allocated to RBS. The bit error rate measures errors on digital channels.

In addition, the MSC 106 stores interference information for the RBSs 103. Such interference information may include:

- Carrier / Interferer (C / I) ratio information. Such information is a measurement of the ratio of the signal strength on a channel when it is being used to communicate with a mobile end unit with the strength of interference signals on that channel. For example, if a channel is not being used in a cell site, the RBS 103 in that cell site may be used to measure the signal strength of signals that are being received on that channel. Such signals may be received because that same channel may be in use for communications in a different cell, in accordance with a channel reuse scheme. This measured signal strength is the interferer signal strength. The signal strength received by the RBS when the channel is being used for communication with an end unit within the cell is the carrier signal strength. The comparison of the interferer signal strength with the carrier signal strength results in a C / I ratio.

In addition, if the cellular telephone network 102 provides digital cellular telephone service, the MSC 106 stores Mobile Assisted Handoff (MAHO) information for mobile end units operating within the service area. In accordance with the IS-54 and IS-136 air protocols, a mobile end unit maintains a MAHO list which contains the signal strengths of the signals that the mobile end unit is receiving over control channels of nearby cells. For further information on these air protocols, see, EIA/TIA Standard 553, "Mobile Station-Land Station Compatibility Specification", September 1989, Electronic Industries Association, Washington, D.C.; EIA/TIA Interim Standard IS-54-B "Cellular System Dual-Mode Mobile Station - Basestation Compatibility Standard", April, 1992, Electronic Industries Association, Washington, D.C.; and EIA/TIA Interim Standard IS-136 "Cellular System Dual-Mode Mobile Station - Basestation:

Digital Control Channel Compatibility Standard", April, 1995, Electronic Industries Association, Washington, D.C., which are incorporated by reference herein. The channels included in a mobile end unit MAHO list are variable, and an indication of which channels to include in the MAHO list is sent to the mobile end unit by the MSC 106. The channels included in a MAHO list generally consist of control channels used in the cells adjacent to the serving cell. Periodically, the MAHO list of a mobile end unit is sent to, and stored in, the MSC 106.

Thus, in one embodiment, the MSC 106 stores the following spectrum information:

1. RBS system performance information;
2. RBS interference information; and
3. Mobile end unit MAHO information.

The FSM 112 receives the spectrum information from the MSC 106 and the spectrum information from the RCDC's 114, processes the information, and makes spectrum management decisions based on the information. The FSM 112 is shown in further detail in Fig. 2. The FSM 112 may advantageously be implemented using a programmed digital computer of the type which is well known in the art. Such a digital computer may be, for example, a personal computer, mainframe computer, minicomputer, or workstation. The overall functioning of the FSM 112 is controlled by a central processing unit (CPU) 202 executing computer program instructions. CPU 202 is connected to a memory unit 204 which contains the computer program instructions (i.e. control program) 206 which are executed by the CPU 202 and control the overall function of the FSM 112. The memory unit 204 also contains rules 208 which are the rules which the FSM 112 uses to manage the spectrum.

The rules 208 may be stored in various ways. For example, rules 208 may be algorithms which describe the actions to be taken based on various input data. Thus, the rules may be in the form of computer program instructions which describe the algorithms. In addition, the rules may be in the form of data tables which correlate input data with associated actions. One skilled in the art would recognize that the rules may take other forms as well. Further various methods of storing rules could be combined. One exemplary rule will be described in further detail below in conjunction with Fig. 5.

The memory unit 204 also stores data 210. Such data 210 includes the spectrum information 226 received from the MSC 106 and the RCDCs 114. Memory unit 204 also contains channel assignment data 220. Channel assignment data 220 contains information indicating which channels are assigned to which cells. In addition, the data 210 includes geographic information 222 which contains information indicating the geographic location of the cell sites. The data 210 also includes working data 224 which the FSM 112 uses during processing. For example, during processing, the FSM will make certain calculations and will need to store intermediate information. Data 210 is advantageously stored in a manner which allows fast access to information needed for analysis by the FSM 112. For example, portions of the data 210 could be stored as a relational database in a well known manner.

Memory unit 204 may be any type of machine readable storage device. For example, memory unit 204 may be a random access memory (RAM), a read only memory (ROM), a programmable read only memory (PROM), an erasable programmable read only memory (EPROM), an electronically erasable programmable read only memory (EEPROM), a magnetic storage media (i.e. a magnetic disk), or an optical storage media (i.e. a CD-ROM). Further, the

FSM 112 may contain various combinations of machine readable storage devices, which are accessible by the CPU 202, and which are capable of storing a combination of computer program code, rules, and data. CPU 202 is also connected to one or more user input devices 212, such as a keyboard, mouse, light pen, touch screen, or microphone, which allow for user input to the FSM 112. A user may be, for example, a network manager who manages the cellular telephone network 102. CPU 202 is also connected to one or more user output devices 214, such as a display screen, printer, or speakers, which allow a user to perceive output generated by the FSM 112. In addition, CPU 202 is connected to a data I/O port 216 which allows the FSM 112 to communicate with external devices. Thus, data I/O port 216 has one or more communication lines 218 which allow the FSM 112 to receive data from, and send data to, external devices, such as MSC 106 and RCDCs 114. One skilled in the art of data communications would recognize that there are various ways to implement a communication channel between the FSM 112 and external devices, including wired and wireless communication channels. The details of such communication techniques will not be described in detail herein.

During operation, the FSM 112 sends requests for spectrum information to the MSC 106 and the RCDCs 114. If the request is to the MSC 106, the request may specify a particular type of spectrum information (e.g. system performance, interference, MAHO) and the request may specify spectrum information from a particular one of RBSs 103. The MSC 106 responds by sending the requested information to the FSM 112. Upon receipt, the FSM 112 stores the requested data as spectrum information 226 in the memory unit 204. Alternatively, instead of the FSM 112 sending requests for spectrum information to the MSC 106, the MSC 106 may be configured to periodically send spectrum information to the FSM 112.

The FSM 112 may also request specific information from the RCDCs 114. As disclosed in copending U.S. Patent application serial no. 08/525,873, the RCDCs 114 may measure and store various types of spectrum information, such as the signal strength of channels operating in the geographic location of the RCDCs 114. Further, the RCDCs 114 may be remotely configurable, in that the FSM 112 may send commands to the RCDCs 114 to request that the RCDCs 114 measure particular characteristics of the spectrum. Upon receipt of information from the RCDCs 114, the received information is stored as spectrum information 210 in the memory unit 204. Alternatively, instead of the FSM 112 sending requests for spectrum information to the RCDCs 114, the RCDCs 114 may be configured to periodically send spectrum information to the FSM 112.

The FSM 112 processes the received spectrum information 210 according to stored spectrum management rules 208. These rules 208 will vary depending on the particular implementation. In general, the rules specify the actions which the FSM will take based on the information received from the external devices. There are three types of actions:

1. Data Request: The FSM 112 may determine that it needs more information in order to made a decision. Thus, the FSM 112 may request further information from the MSC 106 or a RCDC 114. In addition, an information request may include a request that a RCDC 114 begin making certain types of measurements and that the RCDC 114 send the requested information to the FSM 112 when the requested information has been collected.

2. User Recommendation: The FSM 112 may determine that certain spectrum management action would be advantageous, but the rules 208 may specify that such action requires user intervention/approval. Thus, the FSM 112 may output such a recommendation to a user output device 214 indicating the recommended action.

3. Reconfiguration Command: If the FSM 112 determines that certain spectrum management action would be advantageous, and the rules 208 specify that such action may be implemented by the FSM 112, the FSM 112 may take steps to implement the required action. Such action would generally entail sending a reconfiguration command to the MSC 106. For example, if the FSM determines that a channel should be deallocated from one RBS 103 and reallocated to another RBS 103, the FSM 112 would send a radio channel reconfiguration command specifying the required action to the MSC 106. The MSC 106 would then take the appropriate action to reconfigure the RBSs 103. In an alternate embodiment, the FSM 112 sends radio channel reconfiguration commands directly to the RBS 103, or to an intermediate device which controls the RBS 103.

The FSM 112 is an expert system which makes decisions based on stored rules 208. It is noted that the stored rules 208 are rules of the type which, in prior art systems, have been evaluated and applied by engineers performing spectrum analysis. An advantage of the present invention is that these rules are now implemented in an expert system (FSM 112) which can evaluate and implement the rules in real time. Thus, the stored rules 208 may be any type of

rules which heretofore have been evaluated and implemented by engineers. Rules of the type which are suitable to use in conjunction with the present invention are disclosed in, Mobile Cellular Telecommunications Systems, by William C. Y. Lee. ISBN: 0-07-037030-3, McGraw Hill Book Company, 1989, Chapter 8, pages 245-268, which is incorporated herein by reference. The particular types of rules will vary depending on the implementation, and will not be set forth in detail herein.

As shown in Fig. 1, a predictive modeler 116 is connected to the FSM 112. The predictive modeler 116 is connected to a storage device containing modeling data 118. RF engineers often use predictive modelers during the design or modification of wireless systems. Predictive modeling data 118 comprises data which has been collected over time and which is useful in making certain predictions about the wireless system. For example, modelling data 118 may contain data such as RBS 103 locations, antenna types used at different RBS 103 locations, and channel allocations at various RBS 103 locations. The predictive modeler 116 includes a processor executing computer program code which, in conjunction with the modelling data 118, performs various calculations. For example, such calculations may predict the received signal strength at a given location and the potential for interference between multiple RBS 103 sites. In an advantageous embodiment, the predictive modeler 116 augments rules 208, and the FSM 112 uses the predictive modeler 116 in making decisions.

Fig. 1 shows a wireless system which provides a single service (cellular telephone service). However, wireless service providers may provide more than one service, and it is desirable to centrally manage these services when they share radio spectrum. A block diagram of a multiple service system in accordance with the present invention is shown in Fig. 3. Fig. 3

shows a system 300 which contains the cellular telephone network 102 of Fig. 1, a personal base station (PBS) network 302, and a cellular digital packet data (CDPD) network 304. Each of these networks provides a wireless communication service and they share the same frequency spectrum. In an advantageous embodiment, each of these networks are connected to a wireless communication node 306, which provides for communication between the networks, and between the networks and the FSM 112. One skilled in the art would recognize that there are ways of providing communication between the networks other than wireless communication node 306. In the configuration shown in Fig. 3, the FSM 112 is able to manage the shared spectrum across the multiple wireless services.

The system of Fig. 3 is shown in further detail in Fig. 4. The cellular telephone network 102 is as described above in conjunction with Fig. 1. The PBS network 302 comprises a plurality of PBS devices 402 which are connected to the PSTN 108. A PBS 402 is a device which allows a cellular telephone to function as a cordless land-line telephone when used in the vicinity of the PBS. This system allows a user of the cellular telephone to communicate with other land line telephones 110 through the PSTN 108. When the PBS 402 is not communicating with a cellular telephone, it will periodically connect to a private access visitor location register (PA-VLR) 404 through the PSTN 108. Such a PBS network is described in detail in United States patent application serial no. 08/526,066, entitled Wireless Communication System, filed September 8, 1995, which is incorporated herein by reference. (What is referred to herein as a personal base station (PBS) is referred to as a cordless cellular base station (CCBS) in United States patent application Serial No. 08/526,066; and what is referred to herein as a private access visitor location register (PA-VLR) is referred to as a cordless cellular base station visitor location

register (CCBS VLR) in United States patent application Serial No. 08/526,066.) Only a brief description of the PBS network 302 will be described herein. It will be recognized by those skilled in the art that there may be multiple PA-VLR's 404 within the PBS network 302, each of which would have one or more PBSs 402 connecting to it through the PSTN 108. Only one PA-VLR 404 is shown in Fig. 4 to simplify the figure. When the cellular telephone is operating in the vicinity of the PBS 402, the PBS 402 will choose a channel which will be used for communication between the PBS 402 and the cellular telephone. Such a channel is within the frequency spectrum which is assigned to the wireless service provider, and which is used to provide cellular telephone services through the cellular telephone network 102 and CDPD services through the CDPD network 304. Therefore, the PBS 402 must choose a channel that will not interfere with other services provided in the area. A list of possible channels from which the PBS 402 may choose is stored in the PBS 402. This list is controlled by the PA-VLR 404 via communication with the PBS 402. In one embodiment, such communication is accomplished by the PBS 402 periodically initiating a connection with the PA-VLR 404 over the PSTN 108, at which time the PA-VLR 404 may update the channel list stored in the PBS 402.

The CDPD network 304 comprises one or more mobile data base stations (MDBS) 406 in communication with a mobile data intermediate system 408. Such a CDPD network is described in detail in Cellular Digital Packet Data System Specification, release 1.0, July 19, 1993, CDPD System Specification, 650 Town Center Drive, Suite 820, Costa Mesa, CA 92626, which is incorporated herein by reference. Only a brief description of the CDPD network 304 will be described herein. It will be recognized by those skilled in the art that there may be multiple MDISs 408 within the CDPD system 304, each of which would have a plurality of

MDBSs 406 in communication with it. Only one MDIS 408 is shown in Fig. 4 to simplify the figure. As is well known, the MDIS 408 controls the functioning of the MDBSs 406. Such control includes the assignment of radio channels which each MDBS 406 will use to communicate with mobile end units. A mobile end unit in the CDPD network 304 may be, for example, a wireless mobile data terminal. The MDIS 408 is connected to a network 410, such that a mobile end unit may communicate with a land line device or other mobile end units. The network may be, for example, the Internet, or the PSTN.

In accordance with the multiple service embodiment of the invention shown in Figs. 3 and 4, the FSM 112 communicates with the various wireless service networks 102, 302, 304 via the wireless communication node 306. The FSM 112 receives and sends data to the RCDCs 114 as described above.

As described above, mobile end units are devices which communicate with a wireless communication network. It is noted that networks providing different services may communicate with different types of mobile end units. For example, the cellular telephone network 102 may communicate with a mobile telephone, and the CDPD network 304 may communicate with a wireless mobile data terminal. However, it is noted that networks providing different services may also communicate with mobile end units of the same type. For example, the cellular telephone network 102 and the CDPD network 304 may both communicate with a hybrid mobile end unit which is capable of communicating with both networks.

The communication between the cellular telephone network 102 and the FSM 112 is as described above. With respect to the PBS network 302, the PA-VLR 404 stores spectrum information for each of the PBSs 402. Such spectrum information includes channel allocation

data for each of the PBSs 402. This channel allocation data includes a list of channels from which a PBS 402 may choose a channel for communication with a cellular telephone operating in the vicinity of the PBS 402. In addition, spectrum information for a PBS 402 may include system performance information (e.g. blocking rate, dropped call rate, attempt failure rate, out of service statistics, bit error rate statistics) and interference information (e.g. C/I ratio). Such spectrum information may be requested by, and sent to, the FSM 112 via the wireless communications node 306. The FSM 112 is able to control the functioning of the PBSs 402 by sending commands to the PA-VLR 404 via the wireless communications node 306. For example, if the information received by the FSM 112 indicates that a certain PBS 402 is having difficulty finding an acceptable communication channel, the FSM 112 can adjust the channels available to the PBS 402 by sending channel allocation reconfiguration commands to the PA-VLR 404. The PA-VLR 404 in turn will update the list of channels stored in the PBS 402 the next time communication is established between the PA-VLR 404 and the PBS 402 via the PSTN 108.

With respect to the CDPD network 304, the MDIS 408 stores spectrum information of the MDBSs 406 in a manner similar to the manner in which the MSC 106 stores spectrum information of the RBSs 103, as described above. Thus, the FSM 112 receives data from the MDIS 408 via the wireless communication node 306. Further, the MDIS 408 controls the MDBSs 406 in a manner similar to that in which the MSC 106 controls the RBSs 103. Thus, the FSM 112 may send similar control information to the MDIS 408 to control the MDBSs 406.

In the embodiment described above in conjunction with Fig. 1, the FSM 112 manages the radio spectrum with respect to a single service. In the embodiment of Fig. 4, the FSM 112 manages the radio spectrum across various services. However, the basic functioning of the FSM

112 is the same as described above in conjunction with Fig. 1. In the multiple service embodiment, the rules 208 which the FSM 112 uses to manage the spectrum, must take into account the various data available from the different networks and the RCDCs 114. Further, the decisions made by the FSM 112 in accordance with the rules 208 will be more complex, in that a reconfiguration of the spectrum usage in one service may affect other services as well. As stated above, the stored rules 208 are rules of the type which, in prior art system, have been evaluated and applied by engineers during spectrum analysis. The rules for managing spectrum across various technologies are complex, and the present invention implements these rule in an expert system (FSM 112) which can evaluate and implement the rules in real time. Rules of the type which are suitable to use in conjunction with the present invention are disclosed in Mobile Cellular Telecommunications Systems, by William C. Y. Lee, ISBN: 0-07-037030-3, McGraw Hill Book Company, 1989, Chapter 8, pages 245-268, which is incorporated herein by reference. The rules 208 which would be used in a multiple service application would vary depending on the particular application, and such detailed rules will not be described herein. However, for illustration purposes, the following rule algorithm is supplied as an example.

An illustrative rule algorithm is described in conjunction with Fig. 5. Assume for purposes of this description, that this rule algorithm is being carried out with respect to the cellular telephone network 102. It would be recognized by one skilled in the art that this rule could be carried out with respect to the personal base station network 302 or the cellular digital packet data network 304. As described above, the rule algorithm shown in Fig. 5 is implemented as computer program instructions stored as rules 208 in memory unit 204. The program instructions are executed by CPU 202 in order to implement the stored rules.

The rule algorithm is initiated in step 500. In step 502, the system performance information for a cell within the cellular telephone network 102 is analyzed. As discussed above, one type of information received by the FSM 112 from the MSC 106 is system performance information for the RBSs 103 in the cells. This system performance information is retrieved from the spectrum information 226 in the memory unit 204 and the system performance information is analyzed to determine if the demand and supply of channels within the cell are well matched. Such analysis could be based on the blocking rate of the RBS 103 within the cell. The demand may be too high, too low, or well matched, with respect to the supply of channels.

In step 504 the results of the demand analysis are examined. If the demand is too high compared to the supply, then in step 508 it is determined, with reference to geographic information 222 and spectrum information 226, whether spectrum information for the geographic location of the cell being analyzed is available. If the required data is not available, the FSM 112 makes a data request in step 506, and the further processing of this rule algorithm waits for a response. Such a data request may be to the MSC 106 requesting that one of the RBSs 103 connected to the MSC 106 makes certain spectrum measurements and passes those measurements back to the FSM 112 through the MSC 106. The data request may also be to a RCDC 114 in the appropriate geographic area, requesting that the RCDC 114 take certain spectrum measurements and that those measurements be returned to the FSM 112. Upon receipt of the requested information, or if the information is available at the outset, channel quality projections are performed in step 510. During channel quality projections, all, or a portion of, the channels which are available to the wireless service provider are evaluated to determine if any of the channels would provide acceptable quality at the cell (requesting cell) which needs

more channels to satisfy its demand. Those skilled in the art will recognize that there are various ways to determine whether a channel would be acceptable at a particular cell. For example, Carrier/Interferer ratio information could be analyzed to determine the projected quality of a channel at a particular location. In addition, the predictive modeler 116 and the associated modeling data 118, could be used to make predictions regarding the quality of a channel at a particular cell. In step 512 it is determined whether any of the channels analyzed in step 510 would provide acceptable quality. If not, then in step 518 an alarm output is provided to the user. Such an alarm output may be a notice to a user via user output device 214 that a particular cell has demand greater than supply, and that no channel available to the service provider would provide acceptable quality. The rule algorithm would end in step 538.

If it were determined in step 512 that at least one of the channels analyzed in step 510 would provide acceptable quality, then in step 514 inter-service channel analysis is performed on these acceptable channels. Inter-service channel analysis is performed in order to determine whether any of the acceptable channels are available to be assigned to the requesting cell. The FSM 112 accesses channel assignment information 220 to determine if an acceptable channel is already assigned to another cell within the cellular telephone network 102, the CDPD network 304, or to a PBS 402 within the PBS network 302. If it is determined that a channel is assigned to another cell or PBS 402, then the FSM 112 accesses the geographic information 222 and looks up the geographic location of that cell or PBS to determine if the assignment of the channel to the requesting cell would interfere with the existing use of the channel. If the FSM determines that there would not be any interference, then the channel could be assigned to the requesting cell. If the assignment of the channel to the requesting cell would cause interference with the existing

use of the channel, then the channel cannot be assigned to the requesting cell. Such channel analysis is carried out until an acceptable channel is found to be available or until it is determined that no acceptable channels are available.

If it is determined in step 516 that no channels were found to assign to the requesting cell, then an alarm output is sent to the user output device 214 in step 518 indicating that the requesting cell requires addition channel capacity, but that an acceptable and available channel could not be found. The rule algorithm then ends in step 538. If it is determined in step 516 that at least one acceptable channel is available, then in step 520 the channel assignment information 220 is updated, and in step 522 the FSM 112 sends a reconfiguration command to the MSC 106 to command the MSC 106 to assign the channel to the RBS 103 of the requesting cell. The rule algorithm ends in step 538.

Returning now to step 504, if the demand is too low compared to the supply (i.e. there is an oversupply of channels at the cell), then in step 524 it is determined, with reference to geographic information 222 and spectrum information 226 whether spectrum information for the geographic location of the cell being analyzed is available. If the required data is not available, the FSM 112 makes a data request in step 526, and the further processing of this rule algorithm waits for a response. Such a data request may be to the MSC 106 requesting that one of the RBSs 103 connected to the MSC 106 makes certain spectrum measurements and passes those measurements back to the FSM 112 through the MSC 106. The data request may also be to a RCDC 114 in the appropriate geographic area, requesting that the RCDC 114 take certain spectrum measurements and that those measurements be returned to the FSM 112. Upon receipt of the requested information, or if the information is available at the outset, channel quality

analysis for each of the channels currently assigned to the cell are performed in step 528. The channels which are assigned to the cell are determined with reference to channel assignment information 220. Based on the quality analysis, the channel(s) to unassign are determined in step 530. For example, in one embodiment, the channel(s) with the lowest quality may be unassigned. In step 532, an output alarm is sent to user output device 214 to notify a user that the cell had too much supply, and that a channel(s) was unassigned from that cell. In step 534, the channel assignment information 220 is updated to reflect the unassignment. In step 536, the FSM 112 sends a reconfiguration command to the MSC 106 to command the MSC 106 to unassign the channel from the cell. The rule algorithm then ends in step 538.

Returning again to step 504, if the demand and supply at a cell are well matched, then no further processing is necessary, and the rule algorithm ends in step 538.

It is to be noted that modifications could be made to the above rule algorithm. For example, if the FSM 112 determines in steps 514 and 516 that all acceptable channels are currently assigned to other cells, it is possible to program the FSM 112 to make a priority determination as to whether a reassignment of a channel should be made from the cell which currently is assigned the channel to the requesting cell. In such an embodiment, priority information could be stored in data area 210 in memory unit 204. Based on such priority data, the FSM 112 may determine that a cell with higher priority can take a channel away from a cell with lower priority.

The foregoing Detailed Description is to be understood as being in every respect illustrative and exemplary, but not restrictive. It is to be understood that the embodiments shown and described herein are only illustrative of the principles of the present invention and that

various modifications may be implemented by those skilled in the art without departing from the scope and spirit of the invention. For example, the present invention is described in connection with the wireless services of telephone, CDPD, and PBS. However, the invention is not limited to use in connection with such services. The invention could be used to manage radio spectrum with respect to other services.

We claim:

1. A wireless communication system comprising:

a plurality of base stations each capable of communicating with mobile end units over a plurality of radio channels, and each of said base stations having a radio channel configuration;

a switching center in communication with said plurality of base stations, said switching center comprising a memory that stores spectrum information received from each of said base stations;

a frequency spectrum manager in communication with said switching center for receiving said spectrum information, for analyzing said spectrum information, and for sending radio channel reconfiguration commands to said switching center based on said analysis of said spectrum information.

2. The wireless communication system of claim 1 wherein said spectrum information received from said base stations includes blocking information.

3. The wireless communication system of claim 1 further comprising:

a remote data collector in communication with said frequency spectrum manager, said remote data collector collecting spectrum information; and

wherein said frequency spectrum manager receives said spectrum information from said remote data collector, analyzes said spectrum information from said remote data collector, and

wherein said radio channel reconfiguration commands are based, at least in part, on said analysis of said of said spectrum information from said remote data collector.

4. The wireless communication system of claim 3 wherein:

said remote data collector processes said spectrum information prior to sending said spectrum information to said frequency spectrum manager.

5. The wireless communication system of claim 1 wherein said mobile end units are mobile telephones and wherein said wireless communication system provides mobile telephone services.

6. The wireless communication system of claim 1 wherein said mobile end units are cellular digital packet data devices and wherein said wireless communication system provides cellular digital packet data services.

7. The wireless communication system of claim 1 further comprising:

a predictive modeler connected to said frequency spectrum manager, said predictive modeler comprising modeling data;

wherein said frequency spectrum manager analyzes said spectrum spectrum information from said remote data collector.information using said modeling data.

8. A wireless communication system providing a first and second wireless communication service, the system comprising:

a plurality of first base stations each capable of communicating with first mobile end units over a plurality of radio channels in accordance with a first data communication protocol, and each of said first base stations having a radio channel configuration;

a plurality of second base stations each capable of communicating with second mobile end units over a plurality of radio channels in accordance with a second data communication protocol, and each of said second base stations having a radio channel configuration;

a first switching center in communication with said plurality of first base stations, said first switching center comprising a memory that stores spectrum information received from each of said first base stations;

a second switching center in communication with said plurality of second base stations, said second switching center comprising a memory that stores spectrum usage information received from each of said second base stations; and

a frequency spectrum manager in communication with said first and second switching centers for receiving said spectrum information, for analyzing said spectrum information, and for sending radio channel reconfiguration commands to said first and second switching centers based on said analysis of said spectrum information.

9. The wireless communication system of claim 8 further comprising a wireless communications node, wherein said frequency spectrum manager is connected to said first and second switching centers via said wireless communications node.

10. The wireless communication system of claim 8 further comprising:

a remote data collector in communication with said frequency spectrum manager, said remote data collector collecting spectrum information; and

wherein said frequency spectrum manager receives said spectrum information from said remote data collector, analyzes said spectrum information from said remote data collector, and wherein said radio channel reconfiguration commands are based, at least in part, on said analysis of said spectrum information from said remote data collector.

11. The wireless communication system of claim 8 wherein:

said first mobile end units are mobile telephones and wherein said first wireless radio communication service provides mobile telephone services to said mobile telephones; and

said second mobile end units are cellular digital packet data devices and wherein said wireless radio communication service provides cellular digital packet data services to said cellular digital packet data devices.

12. The wireless communication system of claim 8 further comprising:

a predictive modeler connected to said frequency spectrum manager, said predictive modeler comprising modeling data;

wherein said frequency spectrum manager analyzes said spectrum information using said modeling data.

13. The wireless communication system of claim 8 wherein said first and second mobile end units are of the same type.

14. A communication system comprising:

a plurality of personal base stations, each configured to communicate with a mobile telephone operating in the vicinity of the personal base station using a radio channel chosen from a list of radio channels stored in the personal base station;

a private access visitor location register capable of communicating with said plurality of personal base station, said private access visitor location register comprising a memory that stores spectrum information for each of said personal base stations; and

a frequency spectrum manager in communication with said private access visitor location register for receiving said spectrum information, for analyzing said spectrum information, and for sending personal base station reconfiguration commands to said private access visitor location register based on said analysis of said spectrum information.

15. The system of claim 14 further comprising:

a plurality of base stations each capable of communicating with mobile end units over a plurality of radio channels, and each of said base stations having a radio channel configuration;

a switching center in communication with said plurality of base stations and with said frequency spectrum manager, said switching center comprising a memory storing spectrum information received from each of said base stations; and

wherein, said frequency spectrum manager receives said spectrum information from said switching center, analyzes said spectrum information from said switching center, and wherein said personal base station reconfiguration commands are based, at least in part, on the analysis of said spectrum information from said switching center.

16. The system of claim 15 wherein,

said frequency spectrum manager further sends reconfiguration commands to said switching center based on said analysis of said spectrum information from said private access visitor location register and said spectrum information from said switching center.

17. A method for providing wireless communication services comprising the steps of:

providing a plurality of base stations each capable of communicating with mobile end units over a plurality of radio channels, and each of said base stations having a radio channel configuration;

providing a switching center in communication with said plurality of base stations, said mobile switching center comprising a memory that stores spectrum information received from each of said base stations;

providing a frequency spectrum manager in communication with said switching center, said frequency spectrum manager performing the steps of:

receiving said spectrum information from said switching center;

analyzing said spectrum information; and

sending radio channel reconfiguration commands to said switching center based

on said analysis of said spectrum information.

18. The method of claim 17 wherein said frequency spectrum manager further performs the steps of:

determining that additional spectrum information is required in order to send radio channel reconfiguration commands to said switching center; and

sending a request for additional spectrum information to said switching center.

19. The method of claim 17 further comprising the steps of:

providing a remote data collector in communication with said frequency spectrum manager, said remote data collector collecting spectrum information from its environment;

wherein said frequency manager further performs the steps of:

receiving spectrum information from said remote data collector;

analyzing said spectrum information from said remote data collector; and

wherein said step of sending radio channel reconfiguration commands to said switching center is based, at least in part, on said analysis of said spectrum information from said remote data collector.

20. The method of claim 19 wherein said frequency spectrum manager further performs the step of:

determining that additional spectrum information is required in order to send radio channel reconfiguration commands to said switching center; and

sending a request for additional spectrum information to said remote data collector.

21. The method of claim 17 further comprising the step of:

providing a predictive modeler connected to said frequency spectrum manager, said predictive modeler comprising modeling data; and

wherein said modeling data is used in the step of analyzing said spectrum information.

22. A method for providing a plurality of wireless services via a wireless communications system, said wireless communications system comprising a plurality of base stations, each capable of communicating with mobile end units over a plurality of radio channels, and each of said base stations having a radio channel configuration; at least one switching center in communication with said plurality of base stations, said at least one switching center comprising a memory that stores spectrum information received from said base stations; and a frequency spectrum manager in communication with said at least one switching center, said frequency spectrum manager performing the steps of:

receiving spectrum information from said at least one switching center;

analyzing said spectrum information; and

transmitting radio channel reconfiguration commands to said at least one switching center based on said analysis of said spectrum information.

23. The method of claim 22 wherein said frequency spectrum manager further performs the step of:

determining that additional spectrum information is required in order to transmit radio channel reconfiguration commands to said at least one switching center; and

transmitting a request for additional spectrum information to said at least one switching center.

24. The method of claim 22 wherein said wireless communications system further comprises a remote data collector in communication with said frequency spectrum manager, said frequency spectrum manager further performing the steps of:

receiving spectrum information from said remote data collector;

analyzing said spectrum information from said remote data collector; and

wherein said radio channel reconfiguration commands are based, at least in part, on said analysis of said spectrum information from said remote data collector.

25. The method of claim 24 wherein said frequency spectrum manager further performs the step of:

determining that additional spectrum information is required in order to transmit radio channel reconfiguration commands to said at least one switching center; and

transmitting a request for additional spectrum information to said remote data collector.

26. A wireless communication system substantially as hereinbefore described with reference to Figs. 1 and 2, or Figs. 3 and 4, of the accompanying drawings.

27. A method for providing wireless communication services, substantially as hereinbefore described with reference to the accompanying drawings.

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H4L(LDSE)

Int Cl (Ed.6): H04Q

Other:

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB2234142A	NEC CORP eg abstract	all
X	EP0585994A2	PHILIPS PATENTVERWALTUNG whole document	all
X	EP0490554A2	AT&T eg abstract, column 4 line 37 to column 5 line 10	all

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